BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Influence of Sky Brightness and Reflected Sunlight on ATM Coronagraph Operation - Case 610

DATE: October 14, 1968

FROM: T. C. Tweedie, Jr.

ABSTRACT

Successful operation of the ATM coronagraph experiment, S052, requires that the sky brightness and stray light entering the field of view of the instrument optics be less than the dim light of the solar corona being observed. To minimize the possibility of reflected sunlight from the earth's atmosphere entering the field of view of the coronagraph, the Principal Investigator desires to maintain the angle between the coronagraph line of sight and the horizon line at greater than 10°. The magnitude and variation of this horizon reflection angle is determined as a function of the position of the ATM in its orbit for various orbital altitudes and positions of the orbital plane with respect to the earth-sun line, and is related to the time available for coronal observations. At positions in the orbit corresponding to the horizon reflection angle limit of 10°, the sky brightness due to scattering by the tenuous atmosphere along the line of sight is estimated to be an order of magnitude below the brightness of the corona under observation.

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MEMORANDUM FOR FILE

INTRODUCTION

One of the five major solar instruments that is planned for the Apollo Applications Program ATM mission is a white light coronagraph* which will observe and record the brightness, form, and polarization of the solar corona out to 6 solar radii. The dim light of the corona at 6 solar radii is unobservable from the surface of the earth due to a general sky background orders of magnitude higher than the intensity of the corona under investigation. The bright sky background is produced by the earth's atmosphere reflecting and scattering incident sunlight. However, coronagraph measurements made from a manned orbiting spacecraft are essentially free from atmospherically scattered sunlight and the dim light is readily observable.

The baseline ATM mission, on which the coronagraph will be carried, is scheduled to be flown in an approximately 200 NM (380 KM), up to 35° inclination, circular earth orbit. During the daylight portions of the orbits, the coronagraph will record the coronal solar intensities on film which is returned to earth at the end of the 56-day mission.

Two problems peculiar to the successful operation of the coronagraph on the ATM are now examined:

(1) Sunlight reflected off the top of the earth's atmosphere may obliquely enter into the field of view of the coronagraph, producing a background illumination that may compromise the successful operation of the instrument. To prevent this reflected light from entering the field of view, the angle between the instrument's line of sight to the sun and the "top" of the atmosphere must be as large as

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* Experiment S052, White Light Coronagraph, P. I. - Dr. Gordon Newkirk, High Altitude Observatory, Boulder Colorado.

The angle between the line from the center of the earth to the spacecraft and the line from the spacecraft tangent to the horizon θ is given by

$$\sin \theta = \frac{R + y}{R + h}$$

where R - radius of the earth

y - height of atmosphere causing sunlight reflection*

h - orbital altitude of spacecraft

These two equations are solved for $\phi - \theta$, the horizon reflection angle, for various spacecraft altitudes, orbital positions and β angles and the results plotted in Figures 2, 3, 4 and 5. The orbital altitudes considered are 260, 300, 380, and 400 km.

For the currently scheduled ATM mission, Figure 4 illustrates the variation in horizon reflection angle with β and orbital position. Depending on the day and time of launch, and the time into the mission, the magnitude of the β angle can be as high as 58.5° and as low as 0°. For these limits the 10° minimum $\phi - \theta$ angle occurs at the orbital position corresponding to Δ = 107° and Δ = 99° respectively. Based on an orbital rotation rate of 4°/min., this difference in positional angle due to the β angle limit corresponds to a 2 min. change in observation time at sunset and a similar 2 min. at sunrise. Thus the observation time at maximum β angle is 4 min. longer than at minimum β. At maximum β angle, 258° of the total orbital period is in sunlight. Based on the 10° minimum horizon reflection angle, 214° or 83% of the

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* Based on discussions with Dr. Newkirk, 30 km was chosen as a representative value.

possible. In this memorandum, the horizon reflection angle is determined for various positions of the ATM in its orbit as function of ATM altitude and the earth-sun line and compared with the value suggested by the P. I.

(2) Sunlight passing through the earth's atmosphere is scattered producing a general sky brightness. As seen from the orbiting spacecraft, the maximum brightness occurs near sunrise and sunset when the maximum amount of atmosphere is along the line of sight. The magnitude of the sky brightness is estimated to determine if the dim light corona can be observed near these extreme positions.

VIEWING ANGLE

A source of light which may affect the operation of the coronagraph is reflected sunlight from the earth. This reflected light may enter the barrel of the coronagraph and be reflected down the tube onto the film, producing a background luminance in excess of the faint corona under observation. To prevent atmospherically reflected sunlight from entering the barrel, the P. I. desires to maintain the line of sight of the coronagraph at angles greater than about 10° above the horizon.[1] To determine if this limiting situation occurs during an ATM mission, the angle between the line of sight and the horizon line, designated horizon reflection angle, is determined for various combinations of orbital altitude and sun angles.

As shown in Figure 1, ϕ is the angle between a line from the center of the earth to the spacecraft in orbit and the line of sight from the spacecraft to the sun. ϕ is related to the angular orbital position angle of the spacecraft in its orbit Δ and the angle between the orbital plane and the earth-sun line β by

$$\cos \phi = -\cos\beta\cos\Delta$$

$\Delta = 0$ corresponds to spacecraft noon; as Δ increases beyond 90°, the spacecraft is approaching sunset.

sunlight portion* of the orbit is available for coronagraph observations. Correspondingly at $\beta = 0$, 91% of the sunlight portion of the orbit is available for observation.

The field of view of the S052 coronagraph is 1 1/2° half angle. If the horizon reflection angle drops to this value, then the earth's horizon (at R + 30 km) enters the field of view and prevents observation of the complete solar corona. This represents a limit on coronagraph operations.

The possibility of lowering the minimum acceptable value of the horizon reflection angle, $\phi - \theta$, to a value between 10° and 1.5° is possible. For a constant β angle lowering the minimum angle from 10° to 5° allows approximately 2 minutes additional observation time (1 minute at sunrise, 1 minute at sunset); however, additional analysis of the actual scattering paths within the coronagraph barrel are needed before this reduction is possible.

SCATTERED LIGHT

Assuming that the gaseous constituents of the atmosphere scatter sunlight in the visible range of the spectrum isotropically, then the change in solar flux dF after passing a distance dx through a unit cross section of gas is equal to the brightness of the element dB_s radiating in all directions.

$$-dF = N\sigma dx\, B_\odot \omega_\odot = dB_s 4\pi$$

where

- N - number density of scatterers
- σ - cross section for scattering in the visible
- $B_\odot$ - brightness of the sun
- $\omega_\odot$ - solid angle subtended by the sun (6.8×10^{-5} sterad)

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* The percent of daylight in an orbit is given(2) by

$$\% \text{ D.L.} = 1 - \frac{1}{180} \cos^{-1} \left[\frac{\cos\sigma}{\cos\beta}\right]$$

where

$$\sin\sigma = \frac{R}{R + h}$$

Thus

$$\frac{B_s}{B_\odot} = \frac{\omega_\odot}{4\pi} \int N\sigma dx$$

$$\frac{B_s}{B_\odot} = 5.4 \times 10^{-6} \int N\sigma dx \qquad (1)$$

The integral can be evaluated when the path of integration is determined from the actual orbital geometry and the number density of scatters and their scattering cross sections along the path is known.

The cross section for scattering in the Rayleigh limit in which the radius of the scatterer, a, is small compared with a wavelength, λ, is given by[3]

$$\sigma = \frac{10\pi}{3} k^4 a^6$$

$$k = \frac{2\pi}{\lambda}$$

Since the gaseous constituents of the atmosphere at orbital altitudes are primarily atomic and molecular oxygen, and nitrogen, the size of the scatter is in the order of 1-4 Å. The wavelength of interest is 5000 Å. Hence the scattering cross section is in the range 10^{-27} to 10^{-31} m^2. Using the larger value to obtain an upper bound estimate of sky brightness, Equation (1) becomes

$$\frac{B_s}{B_\odot} = 5.4 \times 10^{-33} \int N dx$$

The maximum value of the column density, the integral of Ndx, and hence the maximum value of $B_s/B_\odot$, occurs as the orbiting spacecraft is near sunrise and sunset. From this position, the line of sight to the sun passes through the most dense portions of the atmosphere and thus the integral over the path length yields a maximum column density. For a representative atmosphere, an orbital altitude of 200 nm (380 km) and a minimum ray height of 260 km (point of closest approach of the sun line of sight to the surface of the earth), the column density is $10^{21} - 10^{22} / m^2$. Using this value, the sky brightness relative to the sun as seen from orbit is conservatively

$$\frac{B_s}{B_\odot} = 5.4 \times 10^{-11}$$

At 6 solar radii away from the sun the calculated value for the brightness of the corona B_c, relative to the sun is

$$\frac{B_c}{B_\odot} \cong 6 \times 10^{-10}$$

Thus a conservative estimate of the sky brightness due to scattering is an order of magnitude less than the target of interest and should not interfer with any coronagraph investigations of the K corona. For the conditions considered this value of relative sky brightness occurs at $\Delta = 101°$ for $\beta = 0$ and at $\Delta = 111°$ for $\beta = 58.5°$. Referring again to Figure 4, it is seen that these orbital positions occur after the minimum horizon angle of 10° is attained and hence the sky brightness does not represent a limiting constraint on experiment operations. It is suggested that if possible a sky calibration be performed in orbit to confirm these results.

CONCLUSIONS

By specifying that the coronagraph line of sight to the sun should remain 10° above the horizon, the usable solar observation time is limited to between 83% and 91% of the daylight portion of the orbit. Lowering the limit on the horizon reflection angle increases observation time, but prior to any reduction, additional study on the amount of light that enters the coronagraph and is transmitted to the film is needed to substantiate the change. Sky brightness due to atmospherically scattered light does not appear to be a limiting constraint on ATM orbital coronagraph operation.

T. C. Tweedie Jr.

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REFERENCES

1. Personal Communication with Dr. G. Newkirk, July 30, 1968.

2. B. D. Elrod, "Solar Viewing Capability in High Inclination Circular and Elliptical Earth Orbits," Bellcomm, Inc. TM 68-1022-5, September 5, 1968.

3. W. K. H. Panofsky and M. Phillips, Classical Electricity and Magnetism, Addison-Wesly Publishing Company, 1956.

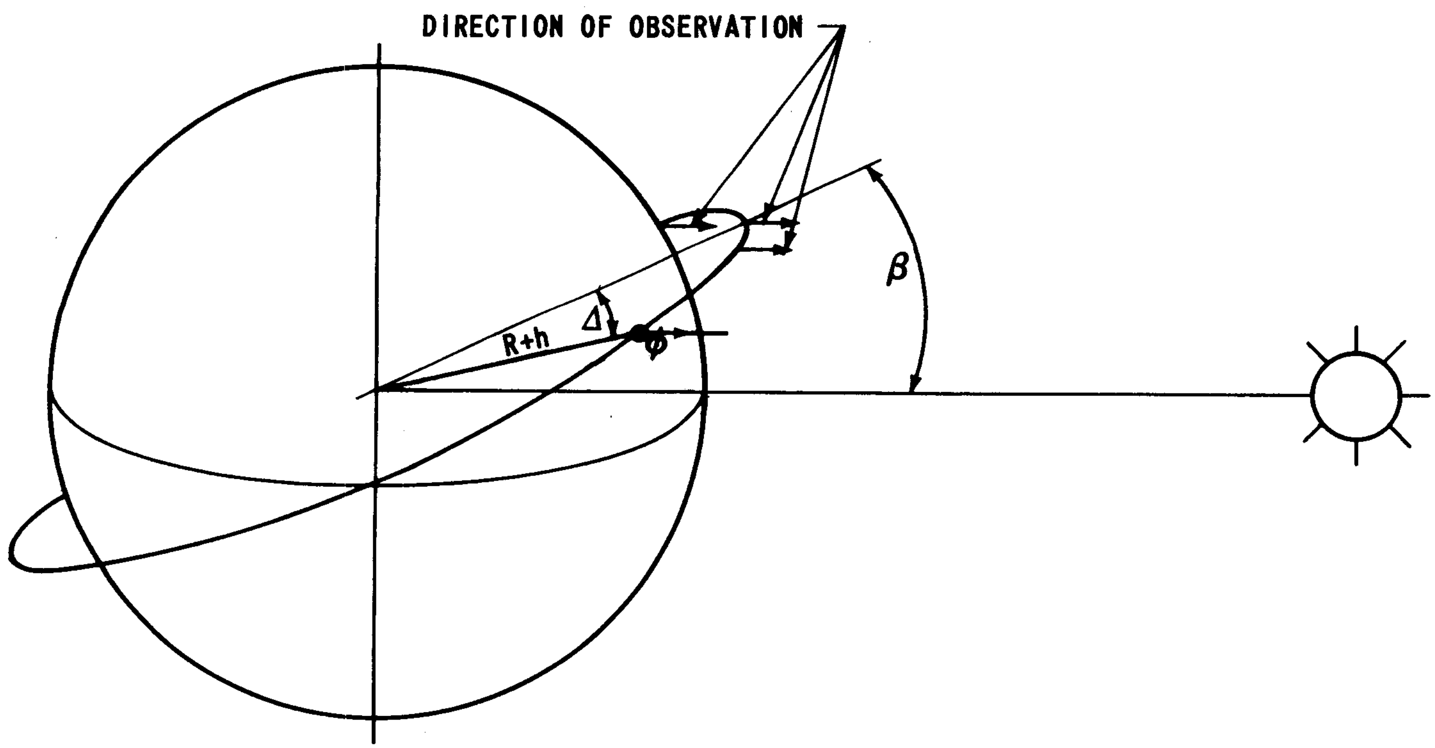

FIGURE 1 - GEOMETRY RELATING SUN ANGLE, ORBITAL PLANE AND SPACECRAFT POSITION IN ORBIT

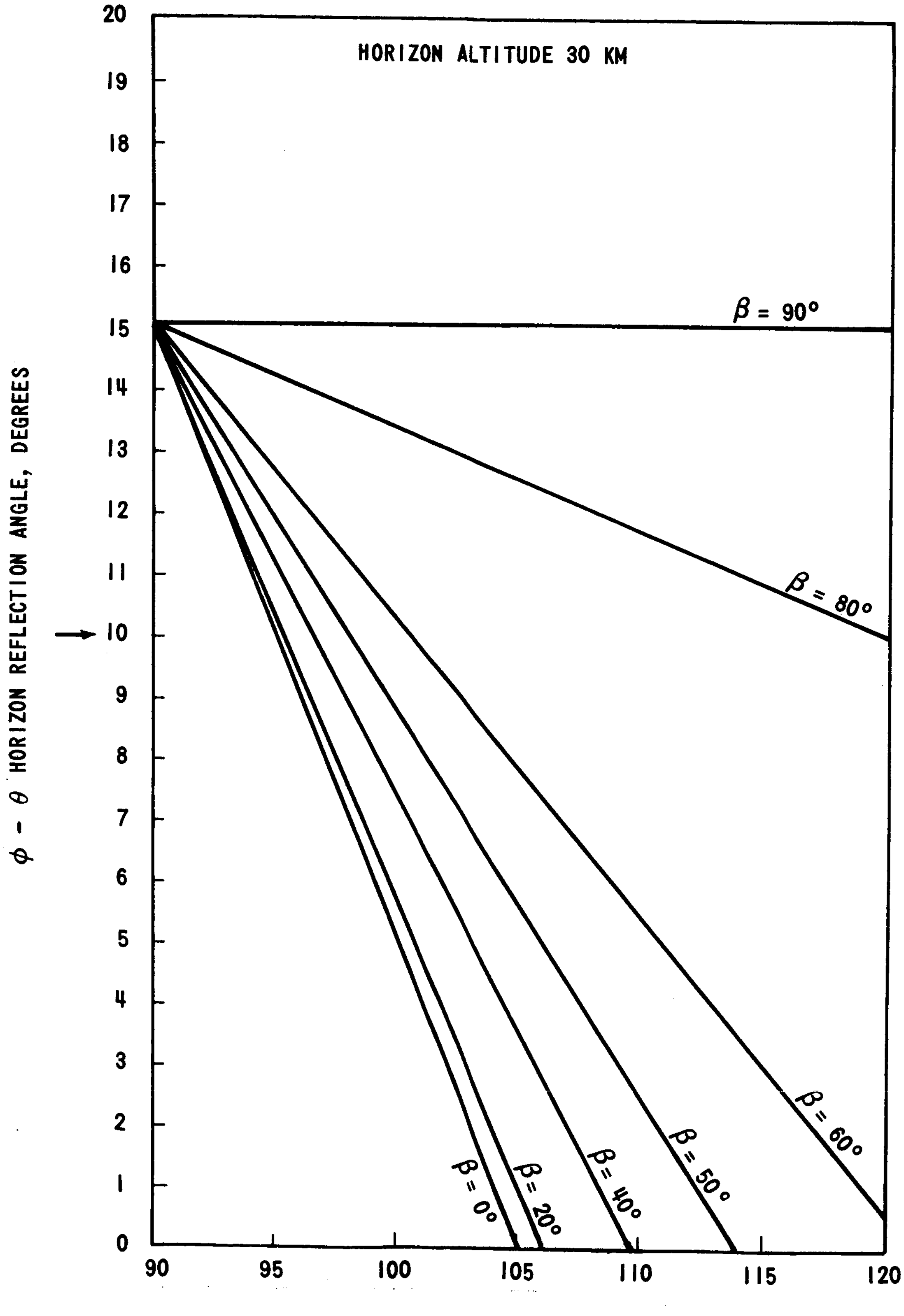

FIGURE 2 - ORBITAL ALTITUDE - 260 KM

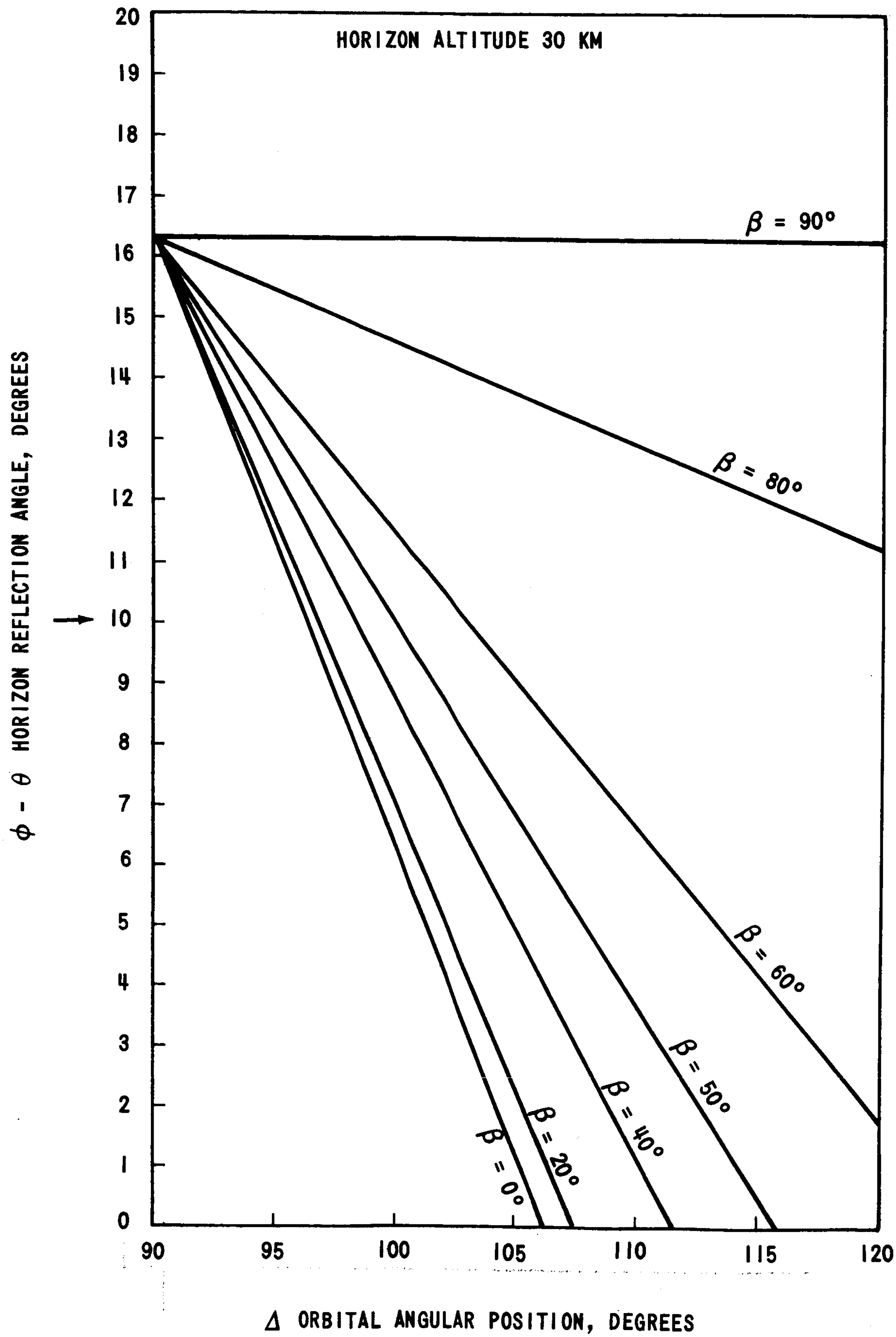

FIGURE 3 - ORBITAL ALTITUDE - 300 KM

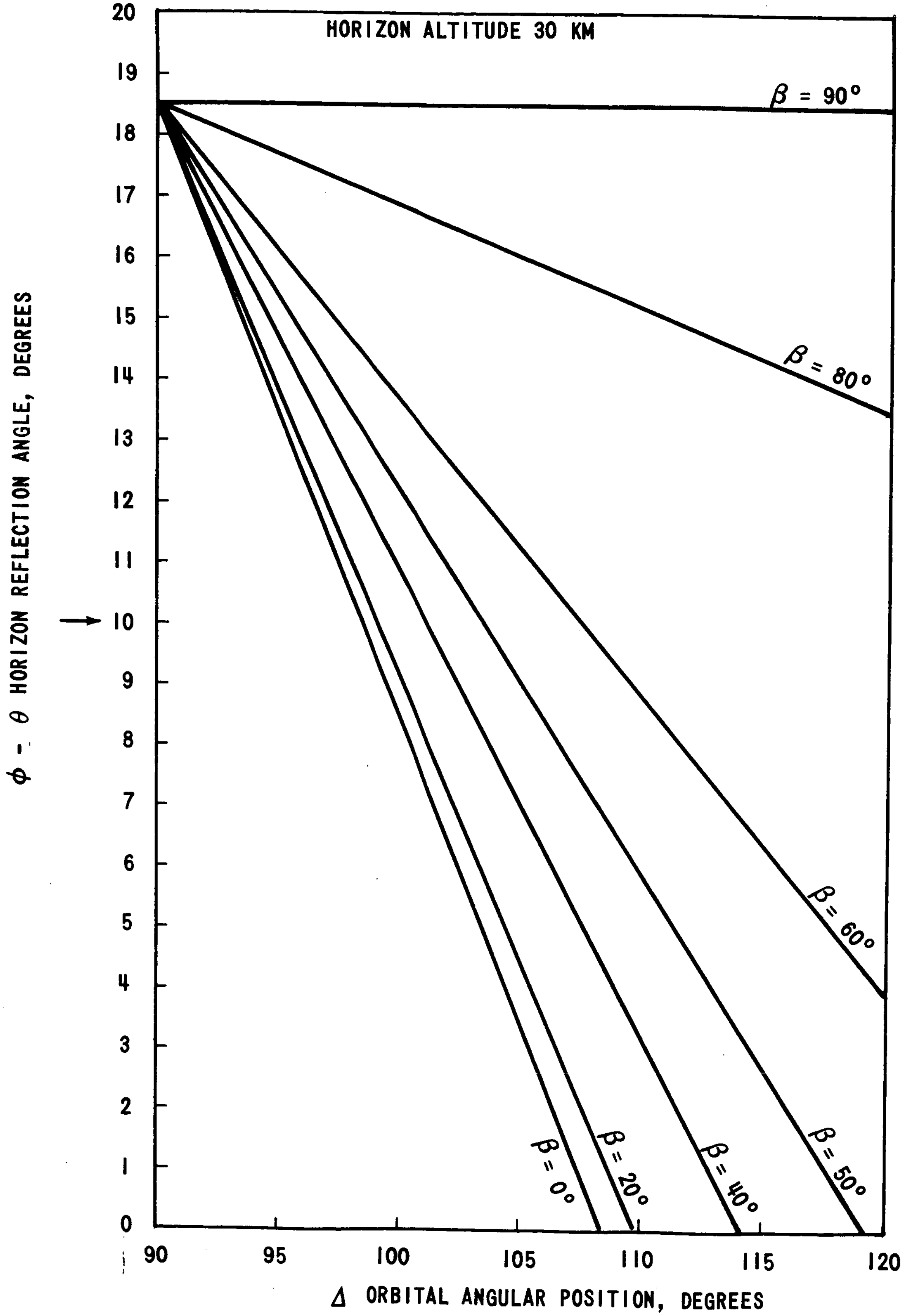

FIGURE 4 - ORBITAL ALTITUDE - 380 KM

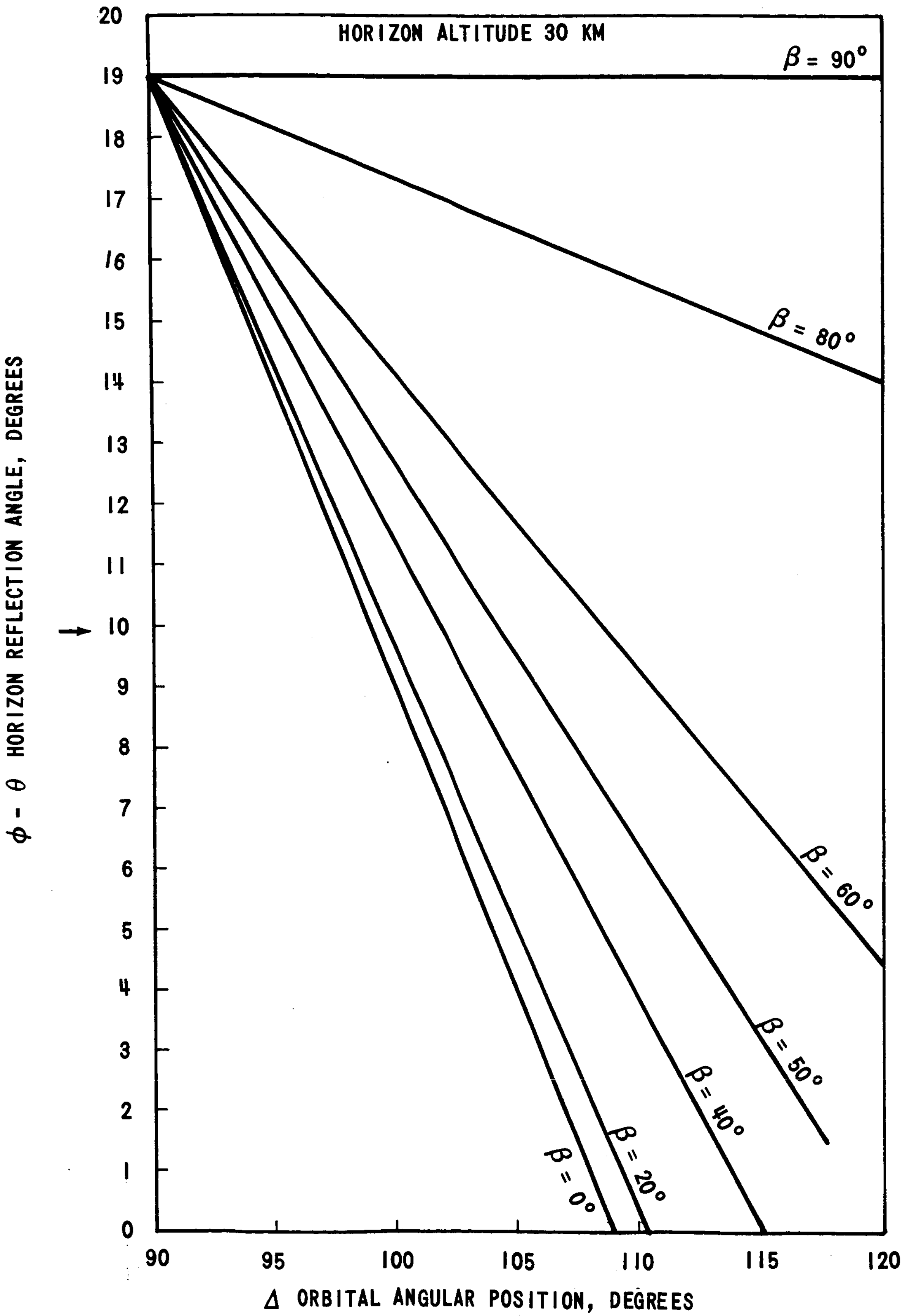

FIGURE 5 - ORBITAL ALTITUDE 400 KM